NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
February 1942 as
Advance Restricted Report

WIND-TUNNEL INVESTIGATION OF AN NACA 23012

AIRFOIL WITH A HANDLEY PAGE SLAT

AND TWO FLAP ARRANGEMENTS

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WASHINGTON

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SUMMARY

An investigation was made in the 7- by 10-foot wind tunnel of an NACA 23012 airfoil equipped with a Handley Page slat and a slotted and a split flap. The purpose of the investigation was to determine the aerodynamic section characteristics of this airfoil with and without flaps, as affected by the location of the Handley Page slat. A range of slat-nose locations was investigated both with and without flaps at a constant slat gap, and the effect of slat gap was investigated for the slotted flap deflected 40°. The slat position for maximum lift, polars for slotted and split flaps for the most favorable slat arrangements for maximum lift, and complete section data for the most favorable slat arrangements are included. Contours of slat-nose location are given for maximum lift coefficient, for angle of attack for maximum lift coefficient, and for drag and pitching moments at selected lift coefficients.

The Handley Page slat in its optimum position on the plain airfoil increased the maximum section lift coefficient by 0.52 and increased the angle of attack for maximum lift coefficient by about 9°. With either the split or slotted flap deflected, the slat increased the maximum lift coefficient of the airfoil-flap combination by about 0.26 and the angle of attack for maximum lift by about 14°. In all cases the drag coefficient at a given lift coefficient was higher with the slat extended than with the slat retracted.

INTRODUCTION

Several previous investigations by the NACA and others have shown that an extensible leading-edge device offers a fair solution to the problems encountered in decreasing landing speeds, which have become increasingly high as wing loadings are increased to obtain greater maximum speeds. The problem of maintaining lateral control over the increased speed range usually resolves itself into one

of maintaining control at low speeds, especially in the presence of lift-increasing devices. The use of high-lift devices brings other associated problems: increased tail load necessary for trim, due to the rearward center-of-pressure travel with flaps, and the abrupt drop in lift at the stall encountered with some high-lift devices.

The extensible leading-edge slat has two separate effects that contribute to the solution of these problems. The slat maintains the air flow over the top surface of the main wing which is kept from burbling up to an angle appreciably beyond the normal stall. The lift is thus maintained for an appreciable range of angles above the normal stall angle. In addition, the slat itself contributes a lift that adds to the lift of the main wing. The total effect is an increased maximum lift, as well as an increased angle of attack for maximum lift. Above the normal stall angle of the airfoil without the slat, the lift increases rather slowly for the airfoil-slat combination. This condition produces a flattening of the lift curve and the slow response of the airplane may serve as a warning to the pilot that the stall is being approached.

The NACA has conducted several investigations of extensible leading-edge slats and of fixed leading-edge slots. The effect of a Handley Page slat on a plain Clark Y wing is given in reference 1. The same slat and wing combination was tested (reference 2) in the presence of a Fowler flap. Data are also included in reference 2 on a modification of the slat. Reference 3 includes valuable air-load data that may be used in the structural design of a leading-edge slat and its associated airfoil. The results of tests of leading-edge slots for both Clark Y and NACA 23012 airfoils with and without flaps are included in references 4 and 5.

The present investigation extends the tests of the previous references to an NACA 23012 airfoil equipped successively with split and slotted flaps. The data for the airfoil-flap combinations alone are given in reference 6.

MODEL

Plain airfoil.- The basic, or plain, airfoil had a chord of 3 foot and a span of 7 foot. It was built to the NACA 23012 profile, the ordinates of which are given in reference 6.

Flaps.- A slotted and a split flap were tested. The slotted flap had a chord of 25.66 percent of the airfoil chord, was designated 2-h in reference 6, and was fastened to the main airfoil as indicated in that reference. The ordinates for the slotted flap are given in figure 1. The split flap had a chord of 20 percent of the airfoil chord and was made of $\frac{1}{4}$-inch plywood. For tests with the split flap, the slotted flap was locked in its neutral position, the gaps at the flap-slot entry and exit were sealed with plasticene, and the split flap was fastened to the airfoil by means of wood blocks that gave the desired flap deflections.

Slat.- The slat, which is shown extended in figure 2, was machined from an aluminum alloy to the ordinates supplied by Handley Page, Ltd., of England. These ordinates are given in figure 1. The slat was made in two pieces, the division being in the center, spanwise, of the slat. Three special fittings were attached to the airfoil, and the nose of the slat (hereinafter referred to as the "slat reference point") pivoted on those fittings in such a manner that the reference point could be located through a wide range of positions. The trailing edge of the slat was held at five points along the span by fittings that also served to set the slat gap.

The nose of the basic airfoil was modified as indicated in figure 1, to accommodate the slat. With the slat fully retracted, the airfoil shape was that of the NACA 23012 airfoil. A small working clearance between the slat and the airfoil was allowed, the slat fitting against the airfoil only at the reference point and at the slat trailing edge in the retracted position.

TESTS

The model was mounted vertically in the test section of the NACA closed-throat 7- by 10-foot wind tunnel so that it completely spanned the jet except for small clearances at each end (reference 6). The main airfoil was rigidly attached to the balance frame by torque tubes which extended through the upper and the lower boundaries of the tunnel. The angle of attack of the model was set from outside the tunnel by rotating the torque tubes with a calibrated drive. Approximately two-dimensional flow is obtained with this type of test installation and the section

characteristics of the model under test can be determined.

All tests were made at a dynamic pressure of 16.37 pounds per square foot, corresponding to a velocity of about 80 miles per hour under standard atmospheric conditions and to a test Reynolds number of about 2,190,000. Because of tunnel turbulence, the effective Reynolds number was 3,500,000 based on a wing chord (slat retracted) of 3 feet and on a turbulence factor of 1.6. The lift, drag, and pitching-moment coefficients were measured in all tests from an angle of attack of -6° to the stall.

The position of the slat reference point was varied, systematically, until the location for maximum lift coefficient was determined for the plain airfoil, for the airfoil with the split flap deflected 60°, and for the airfoil with the slotted flap deflected 40°. The slat gap was maintained at 2 percent of the airfoil chord, the optimum gap from previous investigations. Sufficient data were obtained to plot contours of the slat-reference-point position for various lift coefficients.

For the slotted and split flaps the intermediate flap angles were run with the reference-point location at the location for maximum lift for the flap fully deflected. In these tests the slotted flap was located at the optimum position for each deflection as indicated by reference 6. These positions are also given in figure 7 of the present report. For all tests of the slotted flap at zero deflection, the gaps between the flap and the airfoil were sealed.

In order to check the slat-gap setting of 2 percent of the airfoil chord as the optimum for maximum lift coefficient, tests were made with $1\frac{1}{2}$-percent and $2\frac{1}{2}$-percent slat gaps, the slat-reference-point location being varied to obtain maximum lift. Although insufficient data were obtained to allow the plotting of contours, the maximum lift coefficient with $1\frac{1}{2}$-percent and $2\frac{1}{2}$-percent slat gaps was fairly well determined.

RESULTS

Coefficients.- The test results are given in standard NACA nondimensional section-coefficient form, corrected as explained in reference 6:

c_l ...... section lift coefficient (l/qc)

c_{d_0} ...... section profile-drag coefficient (d_0/qc)

$c_{m(a.c.)_0}$ ...... section pitching-moment coefficient about aerodynamic center of plain airfoil $\left(m(a.c.)_0 \; qc^2\right)$

where

l ...... section lift

d_0 ...... section profile drag

$m(a.c.)_0$ ...... section pitching-moment about aerodynamic center of plain airfoil

q ...... dynamic pressure $(\tfrac{1}{2} \rho V^2)$

c ...... chord of basic airfoil

and

α_0 ...... angle of attack for infinite aspect ratio, degree

δ_f ...... flap deflection measured from flap neutral position, degree

Precision.- The accuracy of the test results is believed to lie within the limits indicated in the following table:

α_0 . . . . $\pm0.1^{\circ}$ c_{d_0} at $c_l = 1.0$ . . . . ±0.0006

$c_{l_{max}}$ ±0.03 c_{d_0} at $c_l = 2.5$ . . . . . ±0.002

$c_{m(a.c.)_0}$ . . . ±0.003 δ_f . . . . $\pm0.2^{\circ}$

$c_{d_{0_{min}}}$ . . . . ±0.0005 Flap and slat positions $\pm0.001c$

No corrections have been applied for the effect of the slat fittings. It is believed that this effect is small and is the same for all tests, and that the relative values of the tests should be unaffected.

DISCUSSION

Effect of slat location on section maximum lift coefficient.- Contours of slat-reference-point location for $c_{l_{max}}$ are given in figure 3 for a slat gap of 0.02c. It may be seen that the presence or absence of the flap has little effect on the optimum location of the reference point for maximum lift. The location of this point is at a slat width of 0.09c and a slat depth between -0.05c and -0.06c. The increment in maximum lift coefficient due to the slat $\Delta c_{l_{max}}$ is 0.52 for the plain airfoil, 0.27 for the slotted flap deflected 40°, and 0.24 for the split flap deflected 60°. On all contour drawings the figure shown at the nose of the airfoil itself is the value for the airfoil with the slat fully retracted.

It appears that a 1-percent variation in width or depth, from the optimum location, makes a change of about $1\frac{1}{2}$ percent in $c_{l_{max}}$. Variation in width, however, is more critical, on the average, than variation in depth.

Effect of slat location on angle of attack for maximum lift coefficient.- Contours of slat-reference-point location for α_0 for maximum lift coefficient, with a slat gap of 0.02c, are presented in figure 4. The location for greatest angle of attack for maximum lift coefficent is approximately the same as the location for greatest maximum lift coefficient. The maximum increment of angle of attack due to the slat $\Delta\alpha_0$ at $c_{l_{max}}$ is approximately 9° for the plain airfoil, 15° for the slotted flap deflected 40°, and 14° for the split flap deflected 60°.

Effect of slat location on section profile-drag coefficient.- Contours of the slat-reference-point location for c_{d_0} at various lift coefficients are shown in figure 5. These contours may prove useful in the selection or determination of glide angle, which is defined as the $\tan^{-1}\frac{D}{L}$. The drag coefficient generally decreases with slat extension upward and forward, and the drag coefficient is appreciably greater with the slat extended than with the slat retracted at the same c_l.

Effect of slat location on section pitching-moment
coefficient.- Contours of the slat-reference-point location
for $c_{m(a.c.)_0}$ at various lift coefficients are shown in
figure 6. The slat has a positive pitching-moment effect,
tending to decrease the negative pitching-moment coeffi-
cient of the airfoil-flap combination. The effect becomes
greater as the slat is moved farther forward and upward.

Aerodynamic section characteristics of airfoil-flap-
slat combination.- The effect of flap deflection on the
aerodynamic section characteristics of the airfoil-slat-
flap combination with the slotted flap is indicated in
figure 7. It may be seen that, above the angle of stall
of the plain airfoil (about 15°), the lift increases less
rapidly with change in angle of attack. The final stall
occurs at approximately 24° or 25°. The break in the lift
curves at 15° is accompanied by a large increase in drag
coefficient for angles of attack greater than 15°. Above
a lift coefficient of about 1.0, the negative pitching-
moment coefficient decreases with increasing lift coeffi-
cient, which corresponds to a forward movement of the
center of pressure of the airfoil.

The aerodynamic section characteristics of the air-
foil with the slat and the split flap at various deflec-
tions are shown in figure 8 for two slat positions. In
figure 8(a) the slat reference point is located at a depth
of -0.06c and in figure 8(b), at a depth of -0.04c. In
both parts of figure 8 the slat width is 0.09c, and the
gap 0.02c. The drag coefficient of the airfoil with the
split flap is higher than that of the airfoil with the
slotted flap for similar conditions, but the pitching-
moment coefficient is considerably lower. The angle of
attack for $c_{l_{max}}$ increases slightly with increasing flap
deflection.

A comparison of the split and the slotted flaps at
maximum deflection is shown in the following table:

Flap	δ_f (deg)	Slat depth (percent c)	$c_{l_{max}}$
Split	60	-0.06	2.78
Split	60	-.04	2.68
Slotted	40	-.06	3.05

Comparison of various airfoil-flap-slat combinations.-
A direct comparison of the slotted and the split flap
characteristics with those of the plain airfoil with the
slat in two locations is made in figure 9. The curves for
the plain airfoil show that the effect on the aerodynamic
characteristics, due to a slight variation in depth of the
slat reference point, is negligible.

The gain in maximum section lift coefficient over the
maximum lift coefficient of the plain airfoil, due to the
addition of the slat and to the deflection of either flap,
is shown in figure 10. The slat alone adds an increment
of lift coefficient of 0.52 at $\delta_f = 0°$ and of about 0.26
at $\delta_{f_{max}}$ for either flap.

A plot showing the change in angle of attack for
$c_{l_{max}}$ at various flap deflections for the airfoil with
and without the Handley Page slat is given in figure 11.
The curves in figure 11 show that flap deflection with the
slat retracted decreases the angle of attack for $c_{l_{max}}$
from that of the basic airfoil, whereas flap deflection
with the slat extended slightly increases the angle of at-
tack for $c_{l_{max}}$.

A comparison of the drag characteristics of both
flaps, with and without the slat extended, is presented in
figure 12. The minimum drag coefficient with the slat ex-
tended is about three times that with the slat retracted.
At take-off lift coefficients (c_l, approximately 1.5), the
drag is slightly higher with the slat extended than with
the slat retracted. Above the maximum lift of the airfoil-
flap combination with the slat retracted, the extension of
the slat causes a large increase in the ratio D/L. In
flight this increase would be equivalent to a steepening
of the glide angle ($\tan^{-1} D/L$).

Figure 13 summarizes the important characteristics of
figures 5 to 12. Because the increased angle-of-attack
range is probably the most important advantage gained
through the use of the slat and because it is the variable
directly under the pilot's control, the characteristics are
plotted with respect to angle of attack. From the pilot's
viewpoint, the flattening of the lift curve is advantageous
as a warning of an approaching stall which would probably
be accompanied by a marked vibration throughout the air-
plane. The decrease in negative pitching-moment coeffi-

cient with increase in angle of attack is desirable because the elevator deflections required for landing may be reduced. It should be noted, however, that there is almost no reduction in pitching-moment coefficient in the lower lift range. The use of a slat will not, therefore, allow a decrease in tail area because the tail size will be determined primarily by the maximum wing pitching moment to be balanced at the design high speed with the flap deflected and the slat extended. The increased angle-of-attack range makes the use of the slat desirable over the aileron portion of the wing in order to improve the lateral stability and control at angles of attack near or above the stall of the basic wing.

Effect of slat gap.- The effect of slat gap is shown in figure 14 for the airfoil with the slotted flap deflected 40°. With a smaller gap, the optimum position of the slat reference point for $c_{l_{max}}$ moved forward and downward; however, a comparison of characteristics at the best locations for $c_{l_{max}}$ shows no appreciable effect with small changes in slat gap.

CONCLUSIONS

1. The Handley Page slat extended the angle-of-attack range about 9° for the plain airfoil and about 14° with optimum deflection of either slotted or split flap.

2. The maximum section lift coefficient of the plain airfoil was increased 0.52 by use of the slat, and the maximum lift coefficient of the airfoil with either flap at optimum flap deflection was increased about 0.26 by the use of the slat. The high drag associated with the increased lift should allow a steeper glide angle.

3. The extension of the slat decreased the negative pitching moments at high lift coefficients with flaps deflected but had little effect in decreasing pitching moments at moderate lift coefficients.

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        Langley Field, Va.

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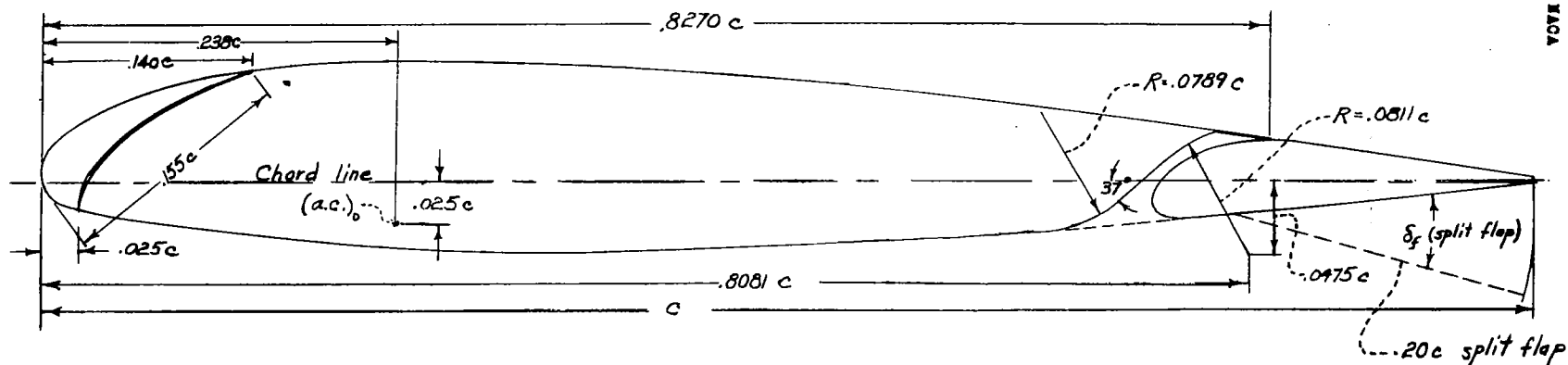
Ordinates given in percent c

NACA 23012 Airfoil Modified		
Station	Upper surface	Lower surface
2.5	[a]-1.71	-1.71
5	2.40	-2.26
7.5	4.25	-2.61
10	5.50	-2.92
14	{7.03 6.99}	-3.39
15	7.19	-3.50
20	7.50	-3.97
25	7.60	-4.28
30	7.55	-4.46
40	7.14	-4.48
50	6.41	-4.17
60	5.47	-3.67
70	4.36	-3.00
80	3.08	-2.16
90	1.68	-1.23
95	.92	-.70
100	.13	-.13

[a]Swing radius from x=6.4, y=-1.71 to include this point.

Handley Page Slat		
Station	Upper surface	Lower surface
0	—	0
1.25	2.67	-1.23
2.5	3.61	[a]-1.71
5	4.91	2.53
7.5	5.80	4.36
10	6.43	5.58
14	7.05	6.99

L E radius 1.58.
Slope of radius: 0.305.

[a]Swing radius from x=6.11, y=-1.49 to include this point.

Slotted Flap		
Station	Upper surface	Lower surface
0	-1.29	-1.29
.40	-.32	-2.05
.72	.04	-2.21
1.36	.61	-2.36
2.00	1.04	-2.41
2.64	1.40	-2.41
3.92	1.94	—
5.20	2.30	—
5.66	—	-2.16
6.48	2.53	—
7.76	2.63	—
9.03	2.58	—
10.31	2.46	—
15.66	1.68	-1.23
20.66	.92	-.70
25.66	.13	-.13

Center of LE arc:
x=0.91 y=-1.29
L.E. radius 0.91

FIGURE 1.— Profile and ordinates of NACA 23012 airfoil with Handley Page slat, slotted and split flaps.

FIG. 1
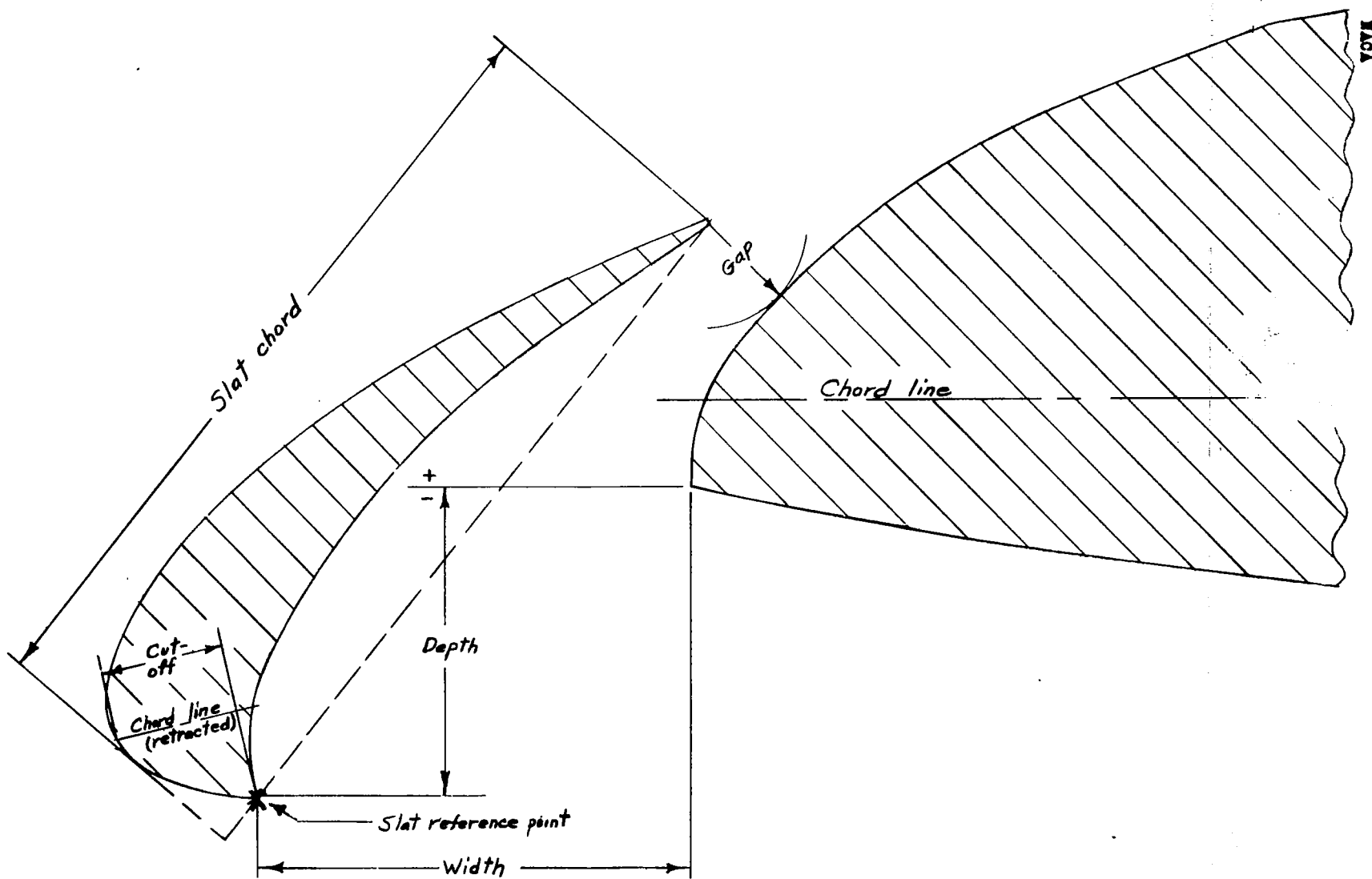
FIGURE 2.—   Handley Page slat on NACA 23012 airfoil.
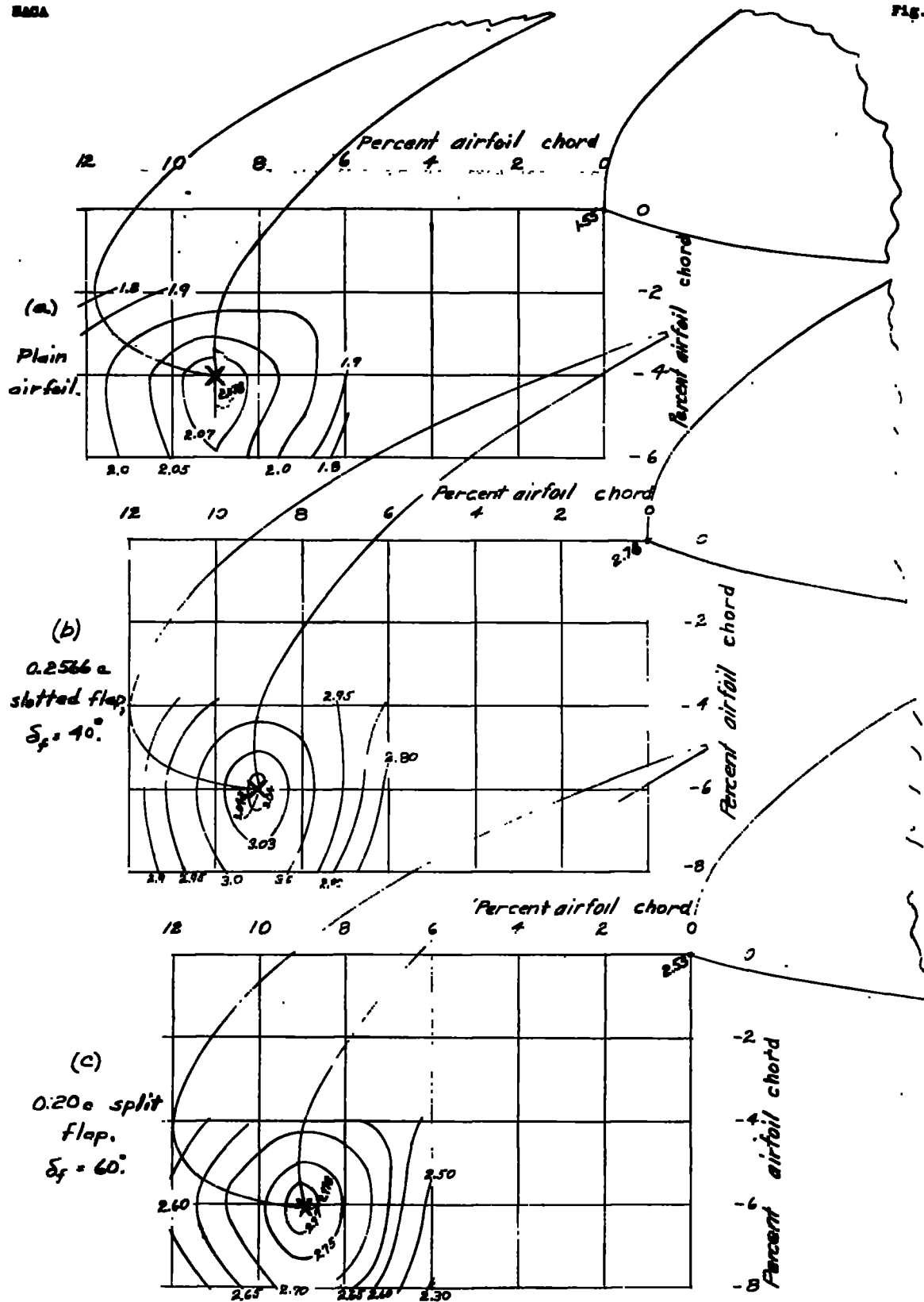
FIGURE 3 — Contours of slat-reference-point location X for $c_{l_{max}}$. Handley Page slat on NACA 23012 airfoil with a slotted and a split flap. Slot gap, 0.02c.
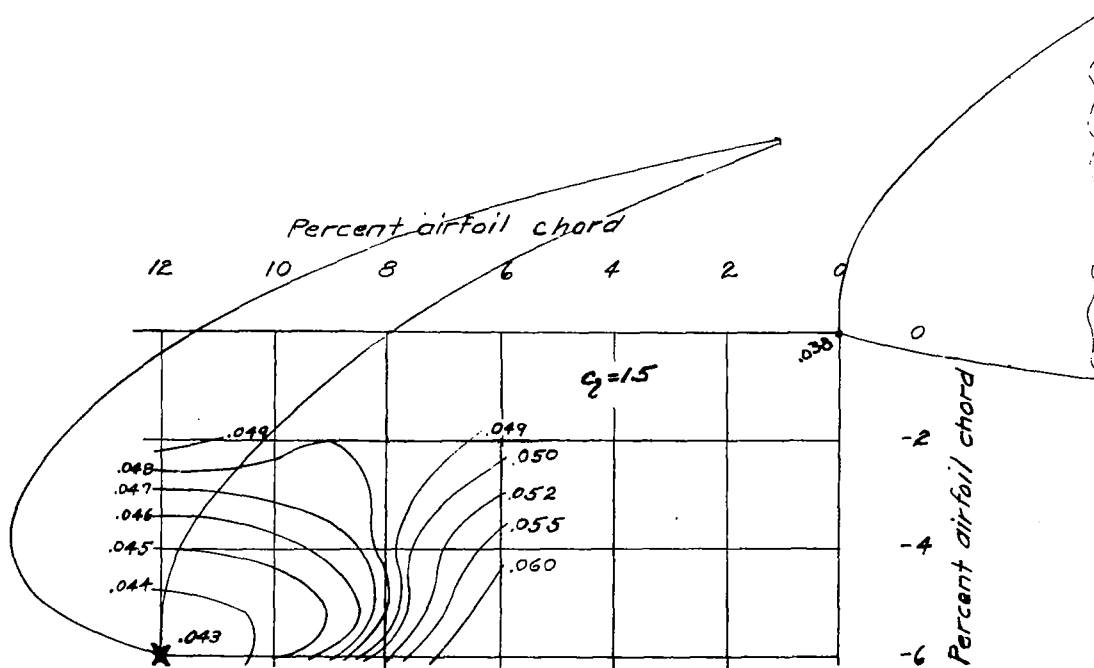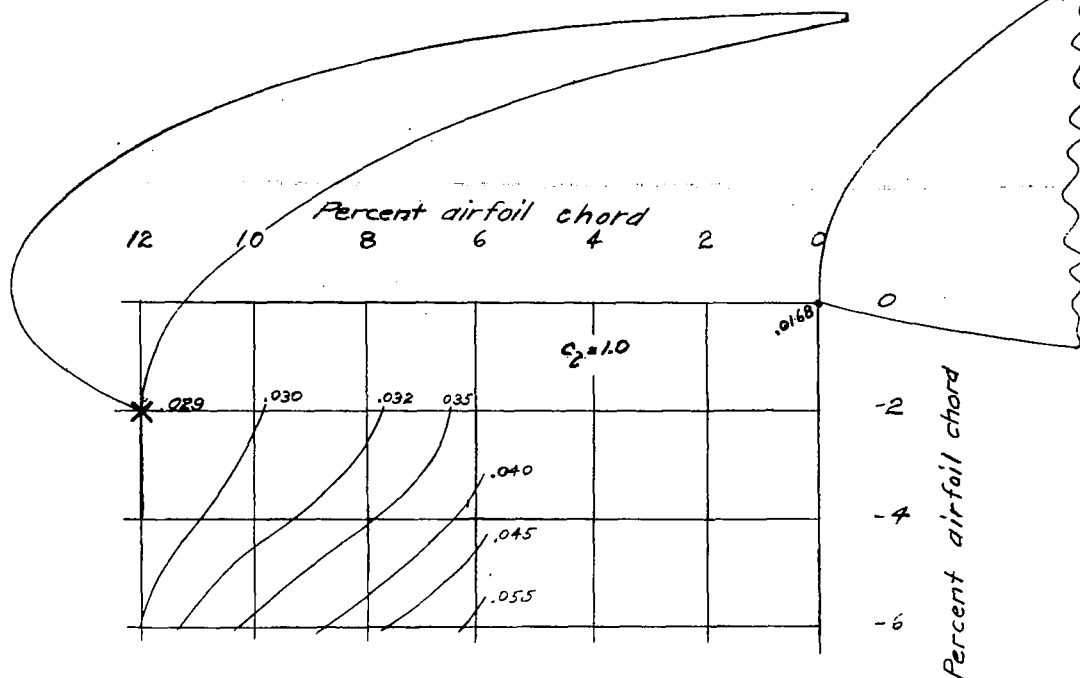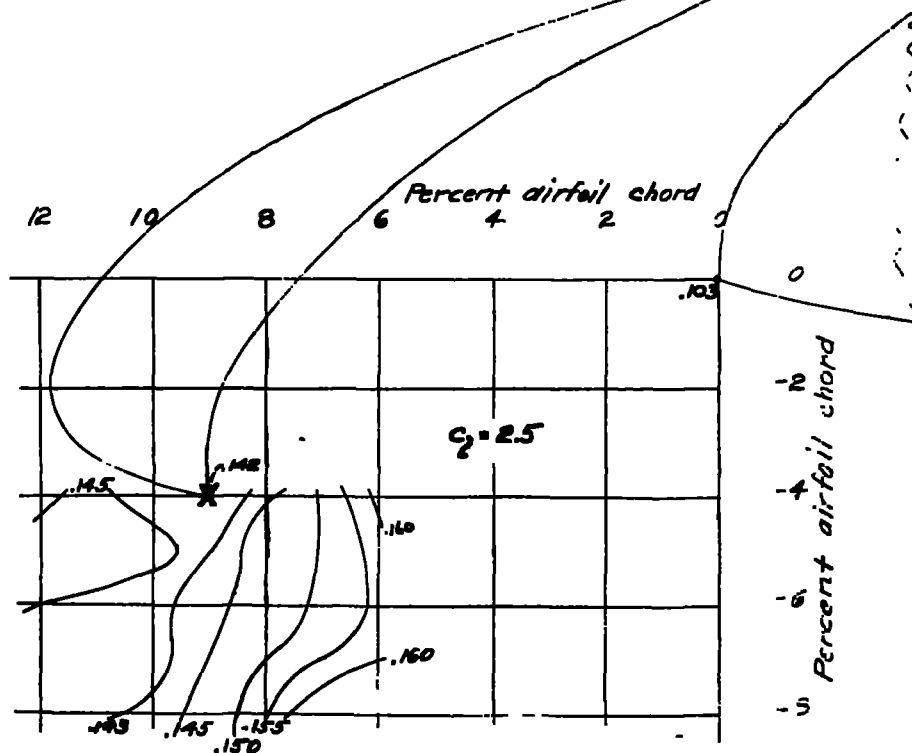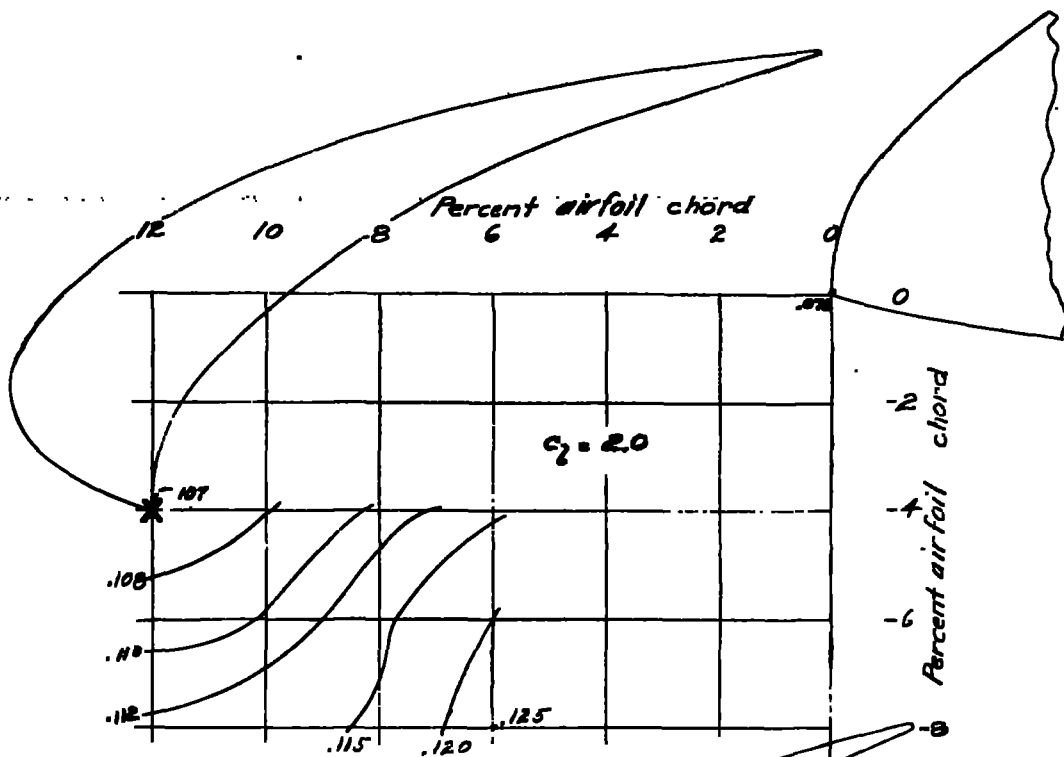
Fig. 4

FIGURE 4.— Contours of slat-reference-point location X for angles of attack of $c_{l_{max}}$; Handley Page slat on NACA 23012 airfoil with a slotted and a split flap. Slat gap, 0.02c.
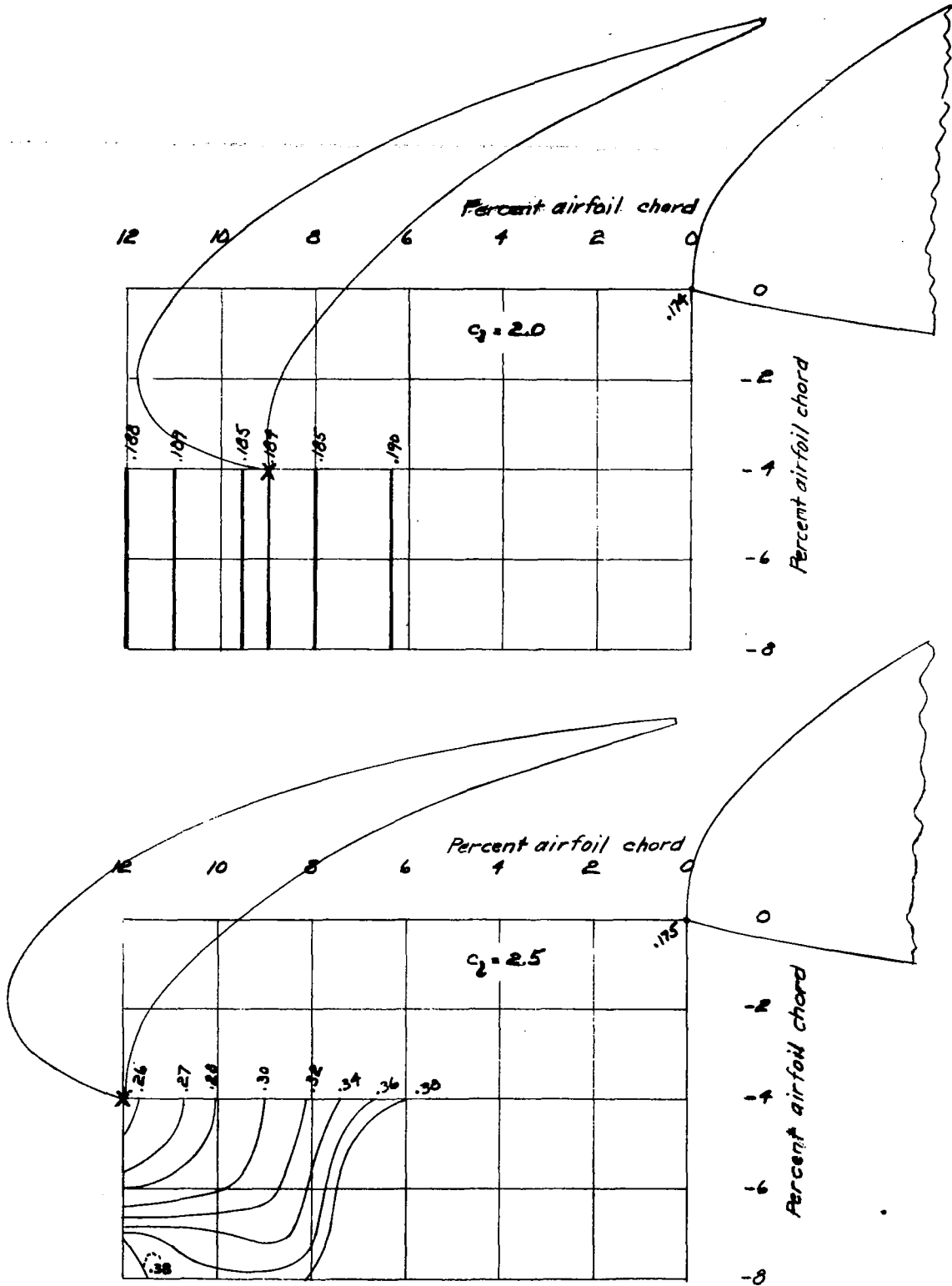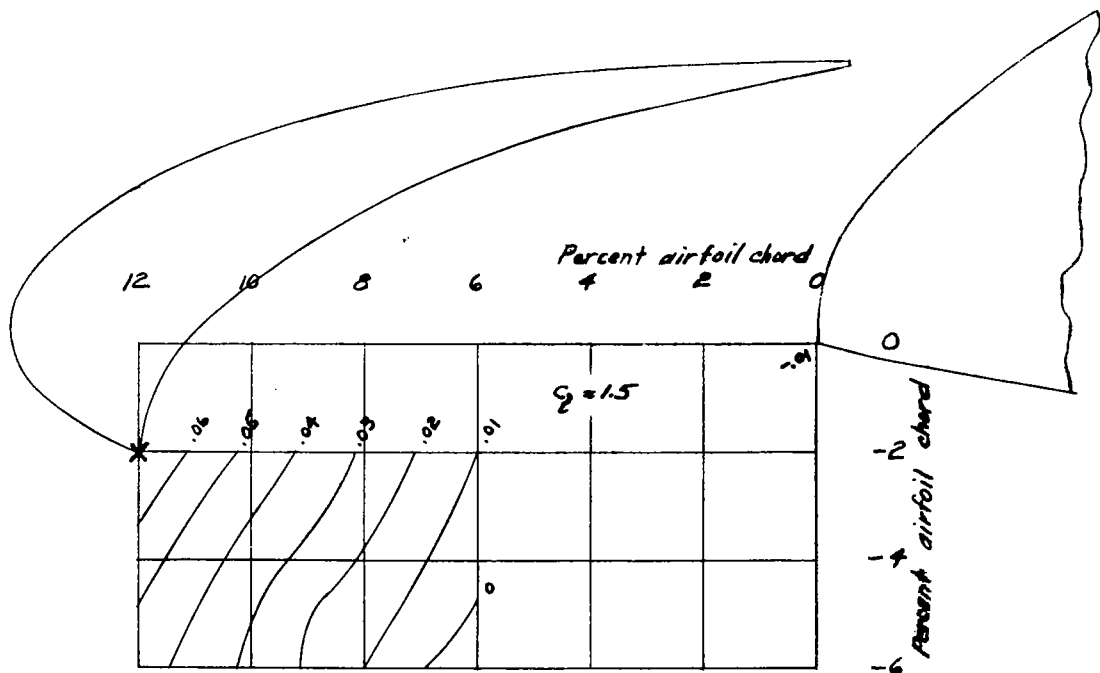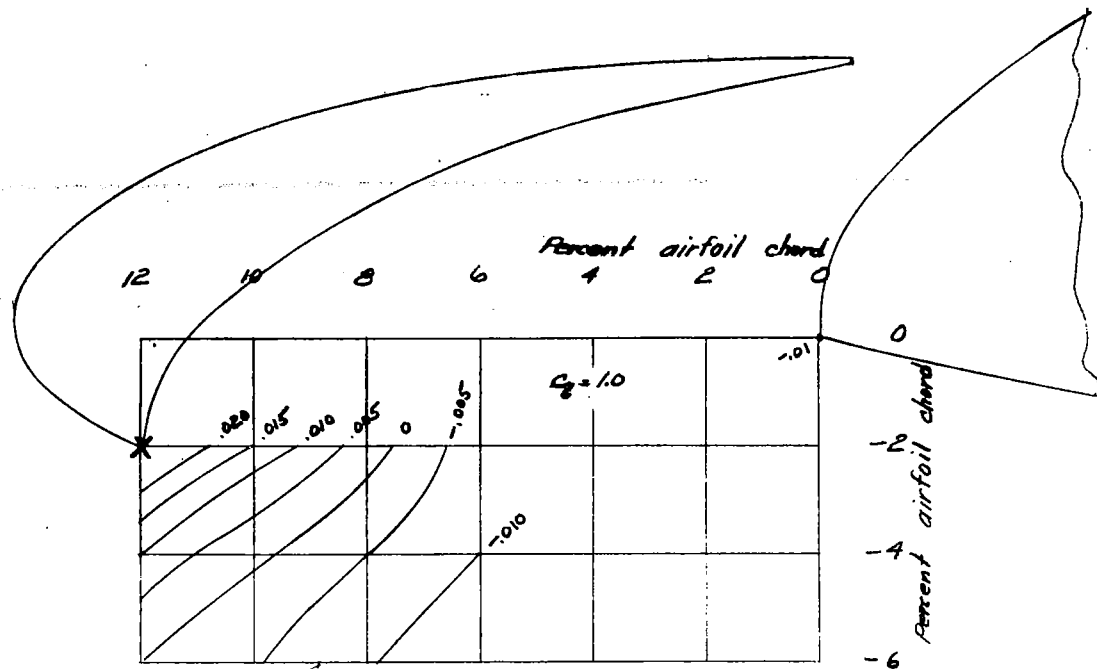
Percent airfoil chord

12   10   8   6   4   2   0

0   -2   -4   -6

Percent airfoil chord

$c_l = 1.0$

.0168

.029   .030   .032   .035

.040

.045

.055

Percent airfoil chord

12   10   8   6   4   2   0

0   -2   -4   -6

Percent airfoil chord

$c_l = 1.5$

.038

.049   .049
.048   .050
.047   .052
.046   .055
.045
.044   .060
.043

(a) Plain airfoil.

FIGURE 5.-   Contours of slat-reference-point location "X" for c_{d_0}.
Handley Page slat on NACA 23012 airfoil. Slat gap, 0.02 c.

(b) Slotted flap deflected 40°

FIGURE 5.— Continued

Percent airfoil chord

$c_j = 2.0$

Percent airfoil chord

Percent airfoil chord

$c_l = 2.5$

Percent airfoil chord

(c) Split flap deflected 60°.

FIGURE 5.- Concluded.

(a) Plain airfoil.

FIGURE 6. — Contours of slat-reference-point location "X" for $C_{m_{a.c.}}$.
Handley Page slat on NACA 23012 airfoil   Slat gap, 0.02c.
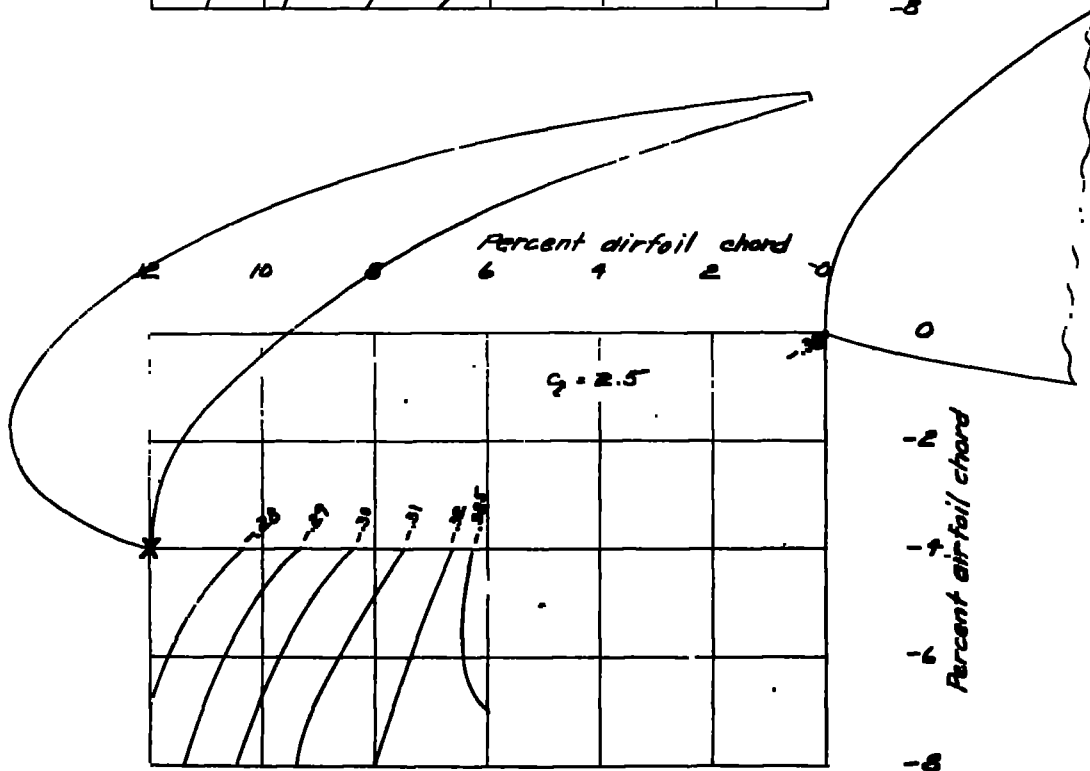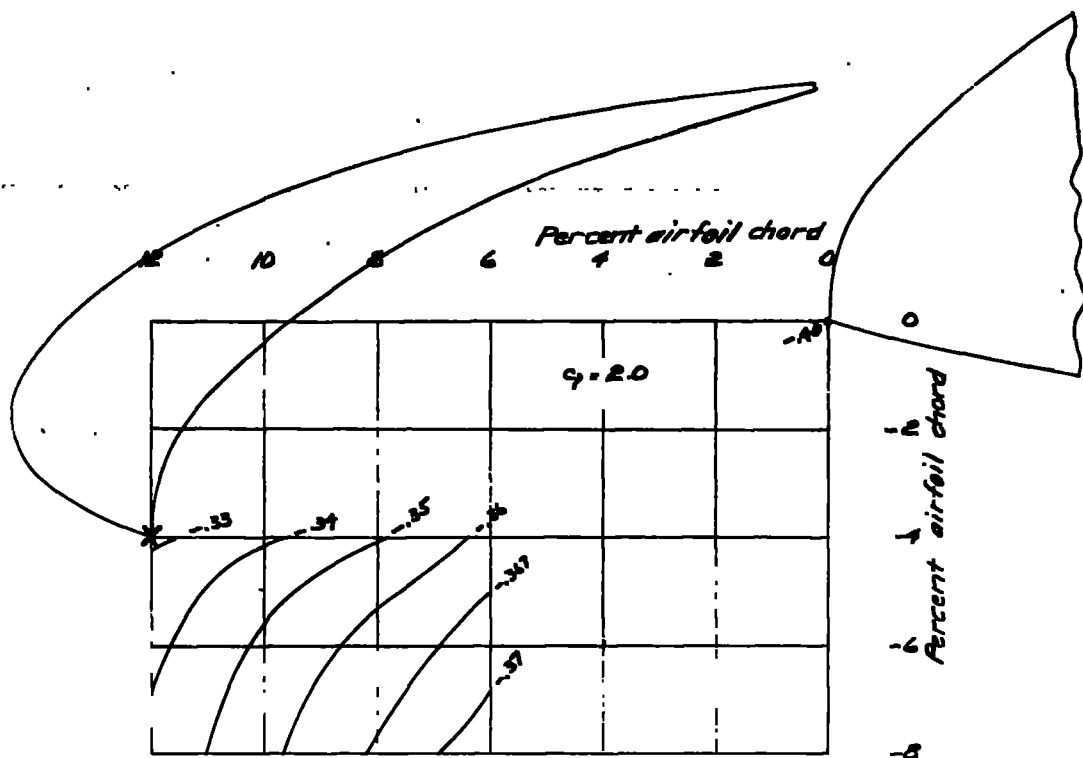
(b) Slotted flap deflected 40°

FIGURE 6. – Continued.

Percent airfoil chord

12   10   8   6   4   2   0

$c_l = 2.0$

-.24

Percent airfoil chord

0

-2

-4

-6

-8

-.18 -.19 -.20 -.21 -.22

-.24

Percent airfoil chord

12   10   8   6   4   2   0

$c_l = 2.5$

-.24

- - - Extrapolated
    Values

-.10 -.12 -.15 -.20 -.30 -.40

Percent airfoil chord

0

-2

-4

-6

-8
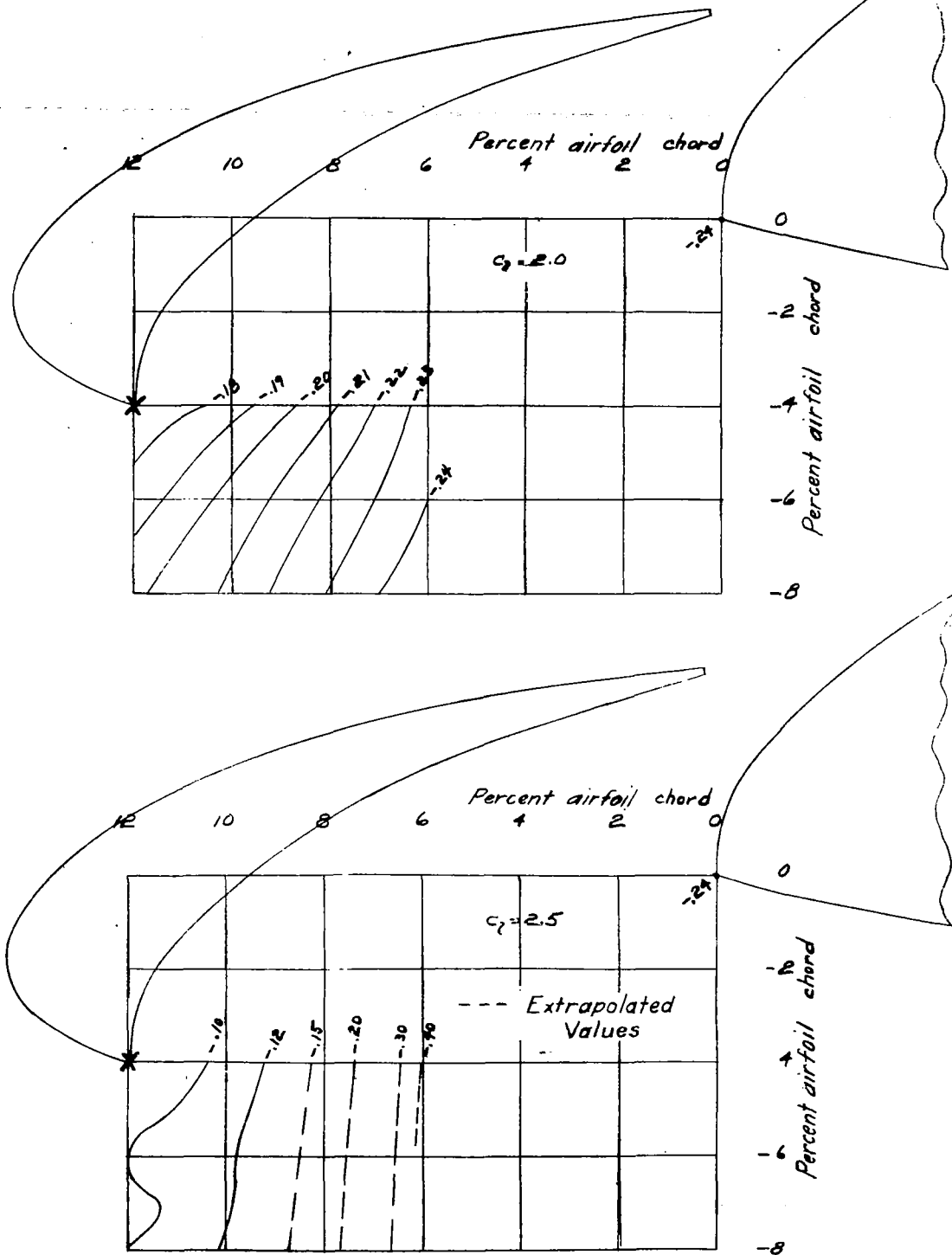
(c) Split flap deflected 60°

FIGURE 6.— Concluded.
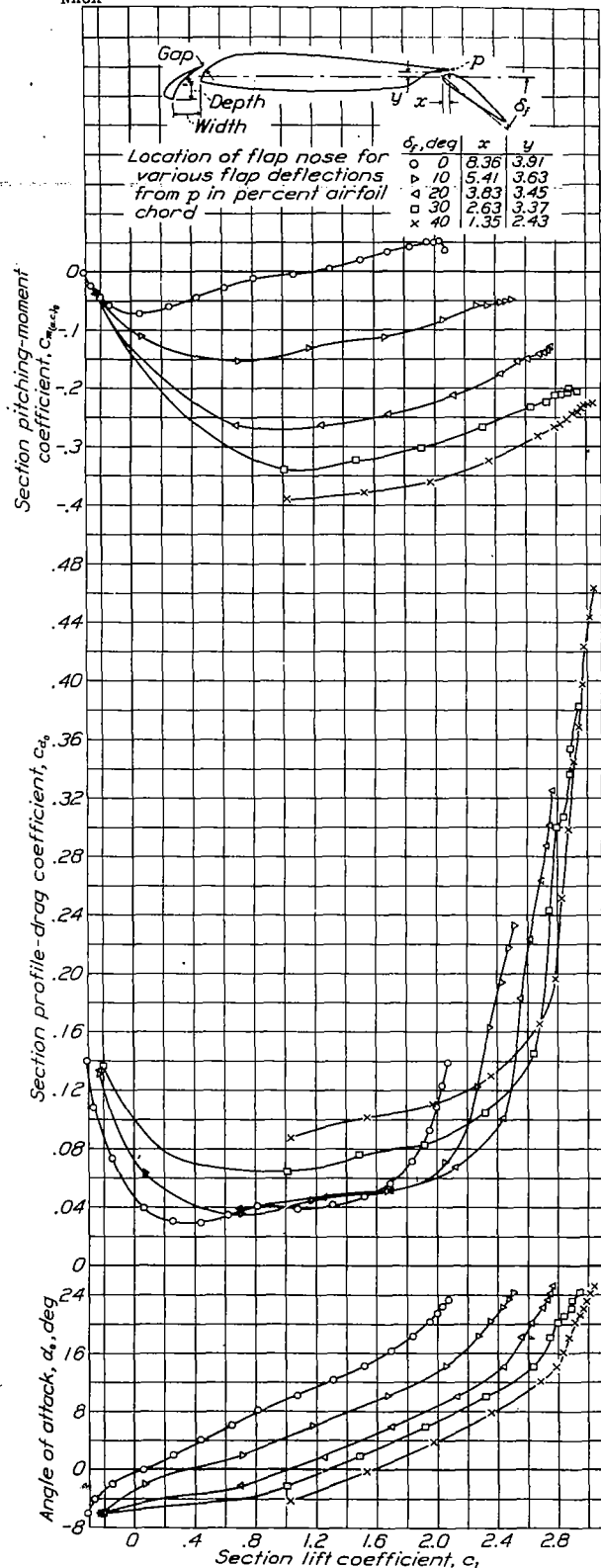
Figure 7.- Aerodynamic section characteristics of NACA 23012 airfoil with a 0.2566c slotted flap and a Handley Page slat. Width, 0.09c; depth,-0.06c; gap, 0.02c.
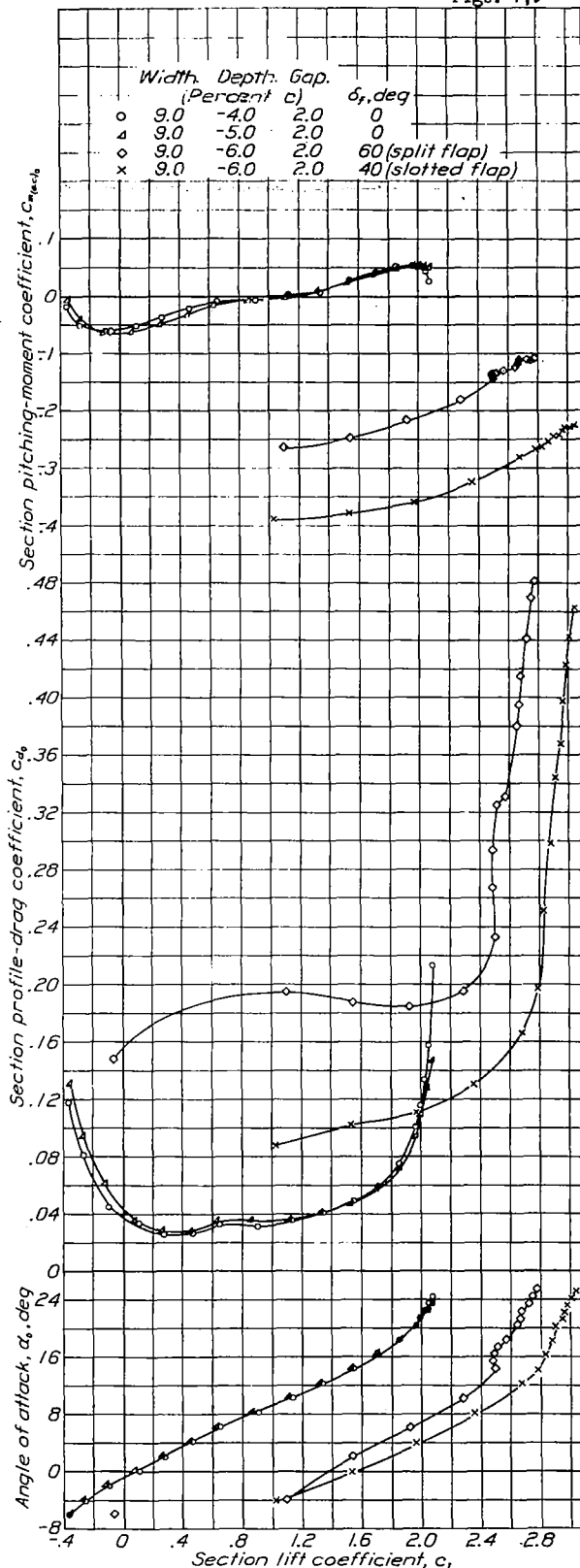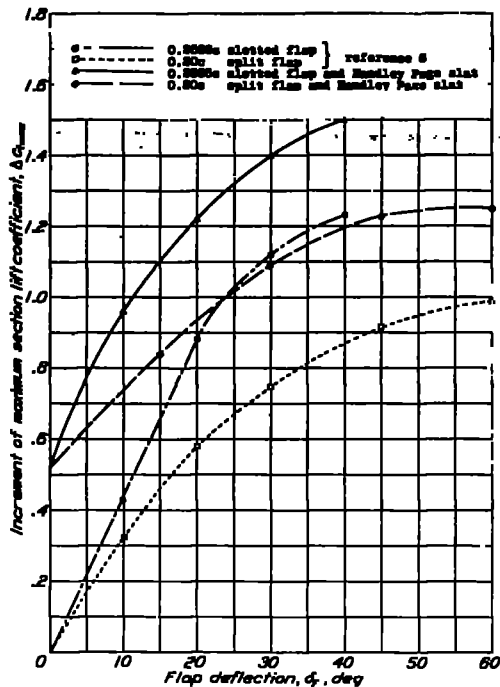
Figure 9.- Aerodynamic section characteristics of NACA 23012 airfoil with and without flaps and with Handley Page slat at optimum location for $c_{l_{max}}$.
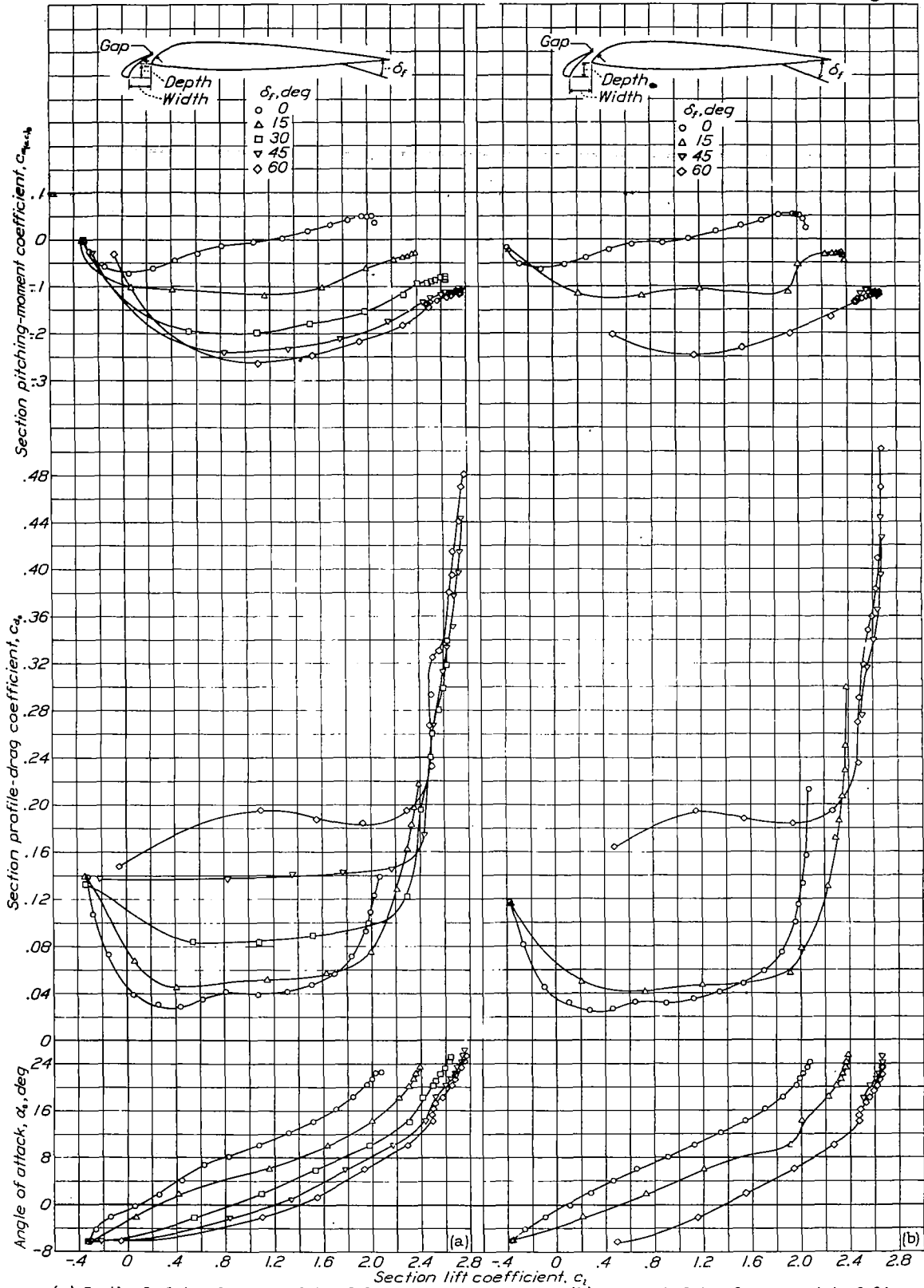
(a) Depth of slat reference point, -0.06c   (b) Depth of slat reference point, 0.04c

Figure 8.- Aerodynamic section characteristics of NACA 23012 airfoil with a 0.20c split flap and a Handley Page slat. Slat width, 0.09c, slat gap, 0.02c.

Figure 10.- Effect of flaps and
             Handley Page slat on
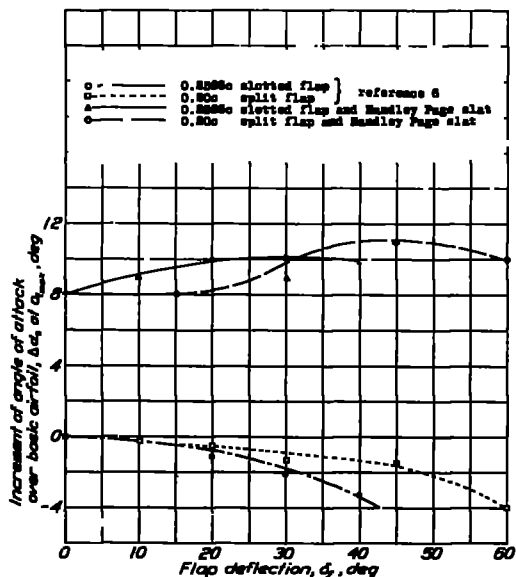increment of maximum section lift
coefficient.

Figure 11.- Effect of flaps and Handley
             Page slat on angle of
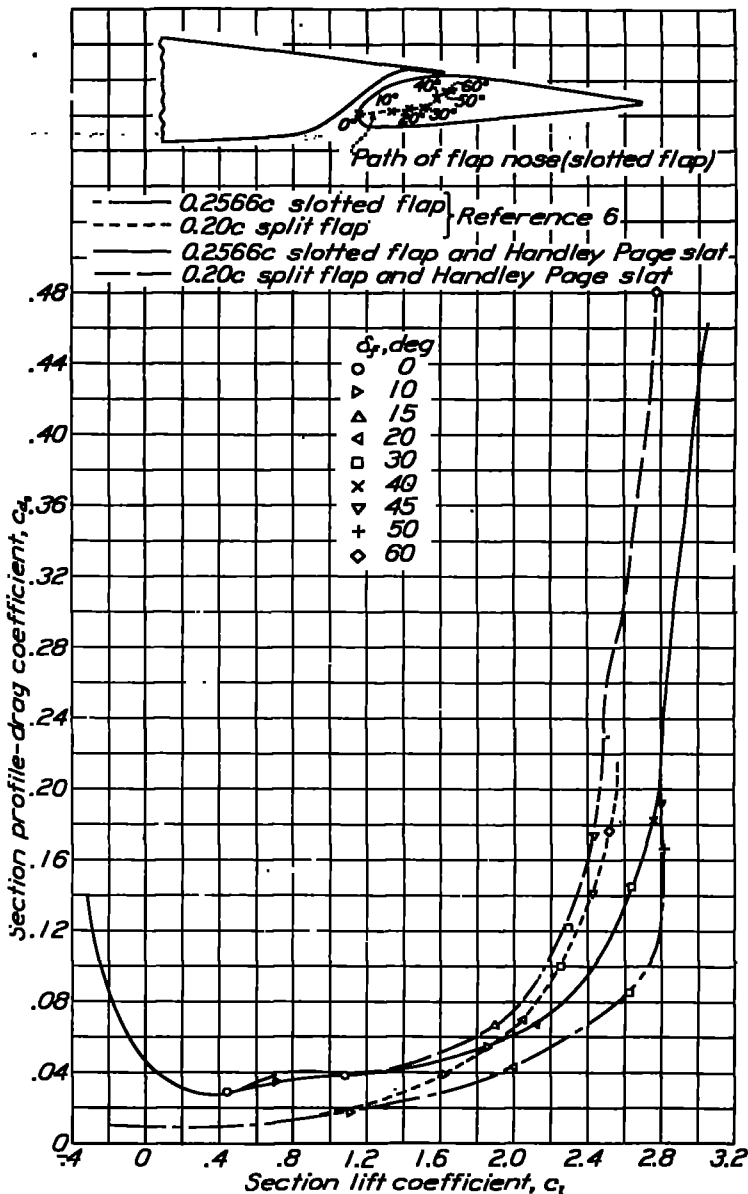attack for maximum lift.

Figure 12.- Comparison of profile-drag coefficients of NACA
            23012 airfoil with two types of flaps and a
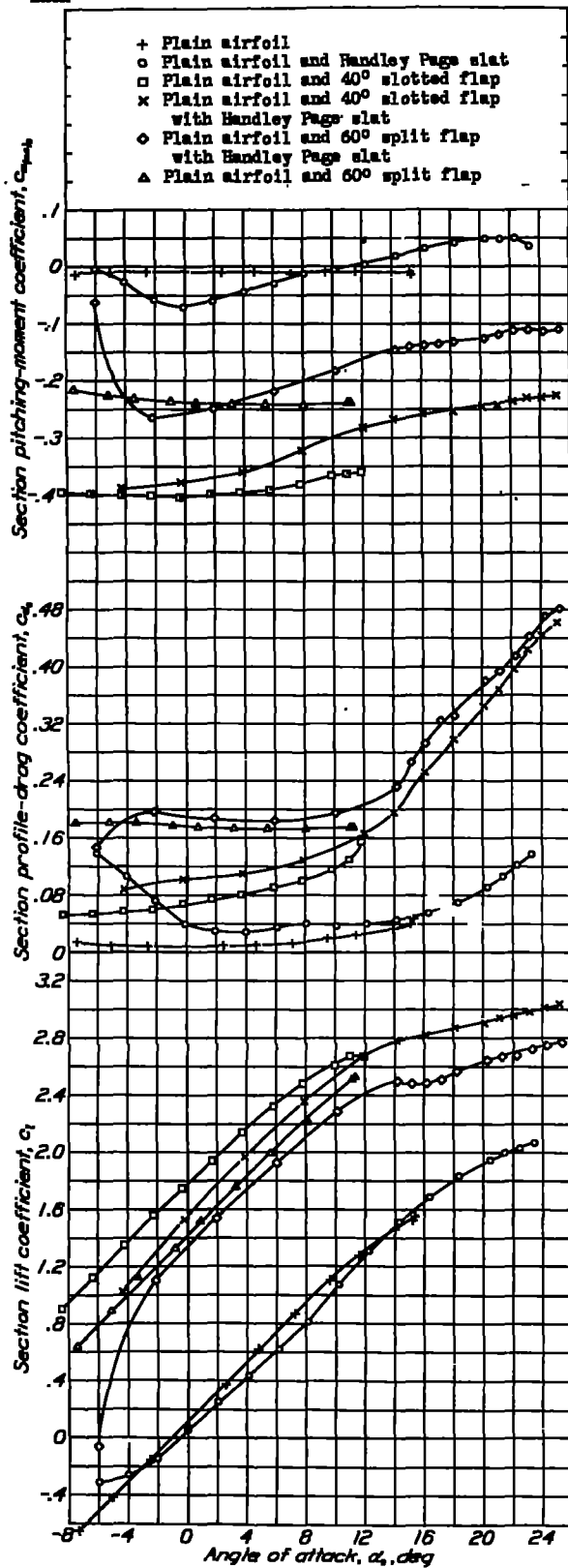Handley Page slat.

Figure 13.- Effect on aerodynamic section characteris-
tics of the NACA 23012 airfoil due to the
addition of two types of flaps and a Handley Page slat.
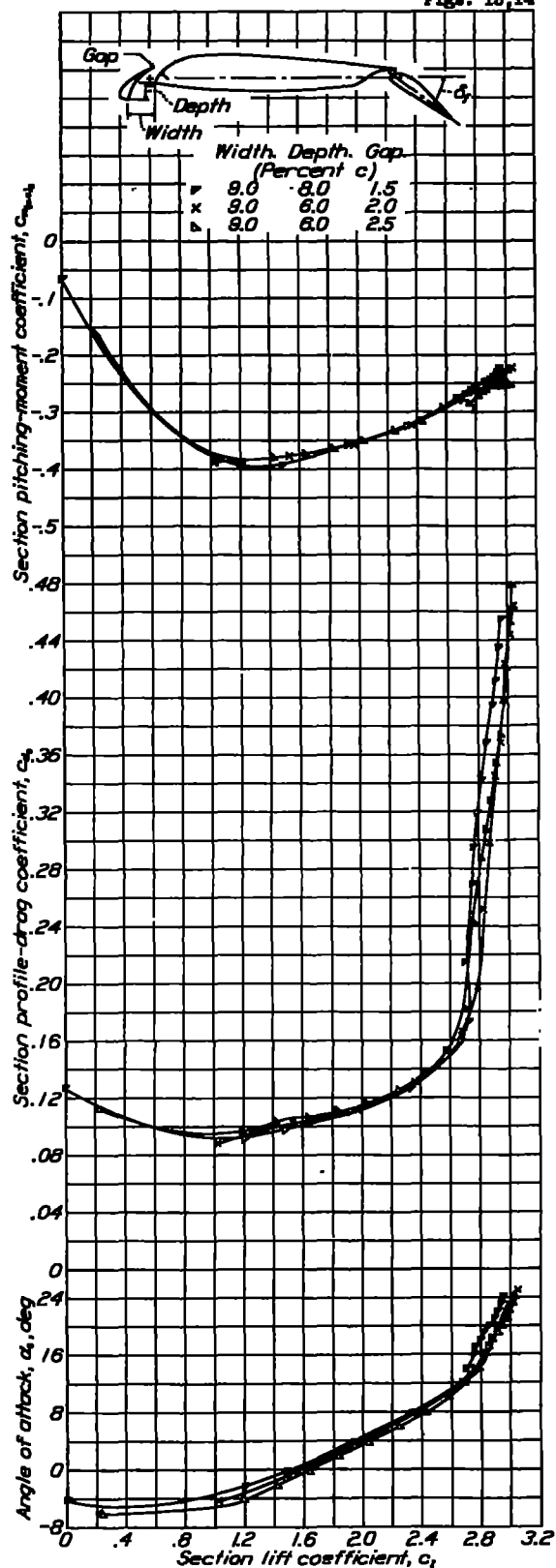Slat location optimum for $c_{l_{max}}$.

Figure 14.- Effect of slat gap on aerodynamic section
characteristics of NACA 23012 airfoil
with 0.2566c flap deflected 40° and slat at optimum
location for $c_{l_{max}}$